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Uncertainties in models for glacial isostatic adjustment

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Uncertainties in models for glacial isostatic adjustment

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GGFC Workshop

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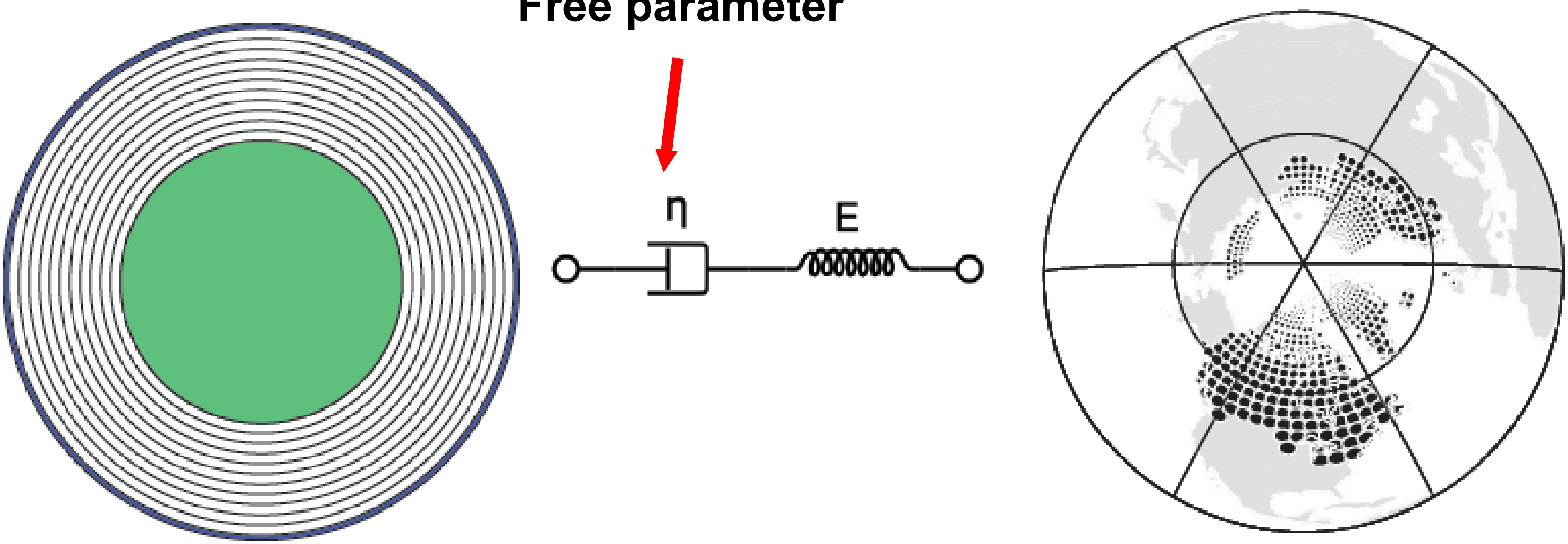
Standard GIA model

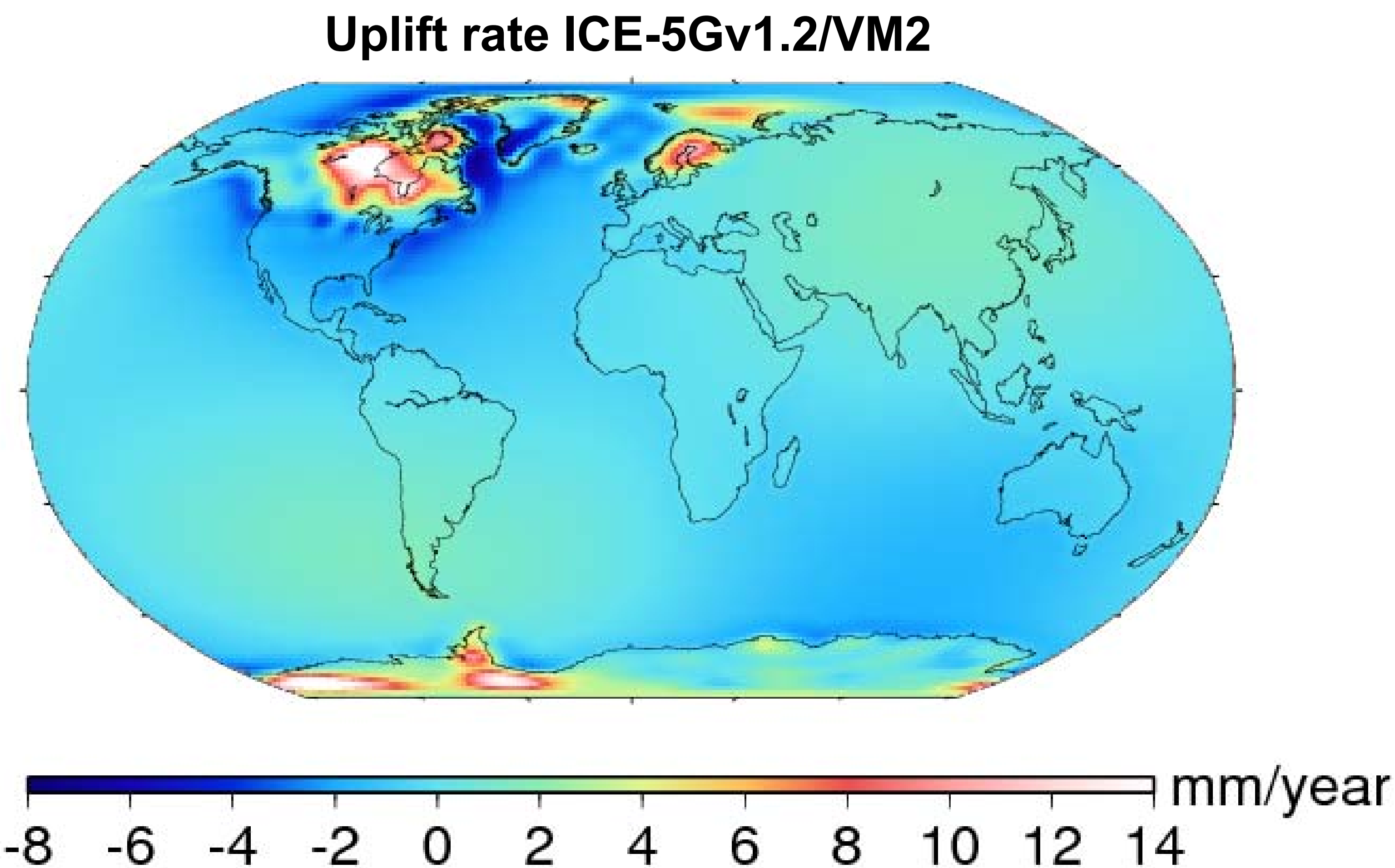
Free parameter



From: Paolo Stocchi, IMAU Utrecht

STANDARD MODEL

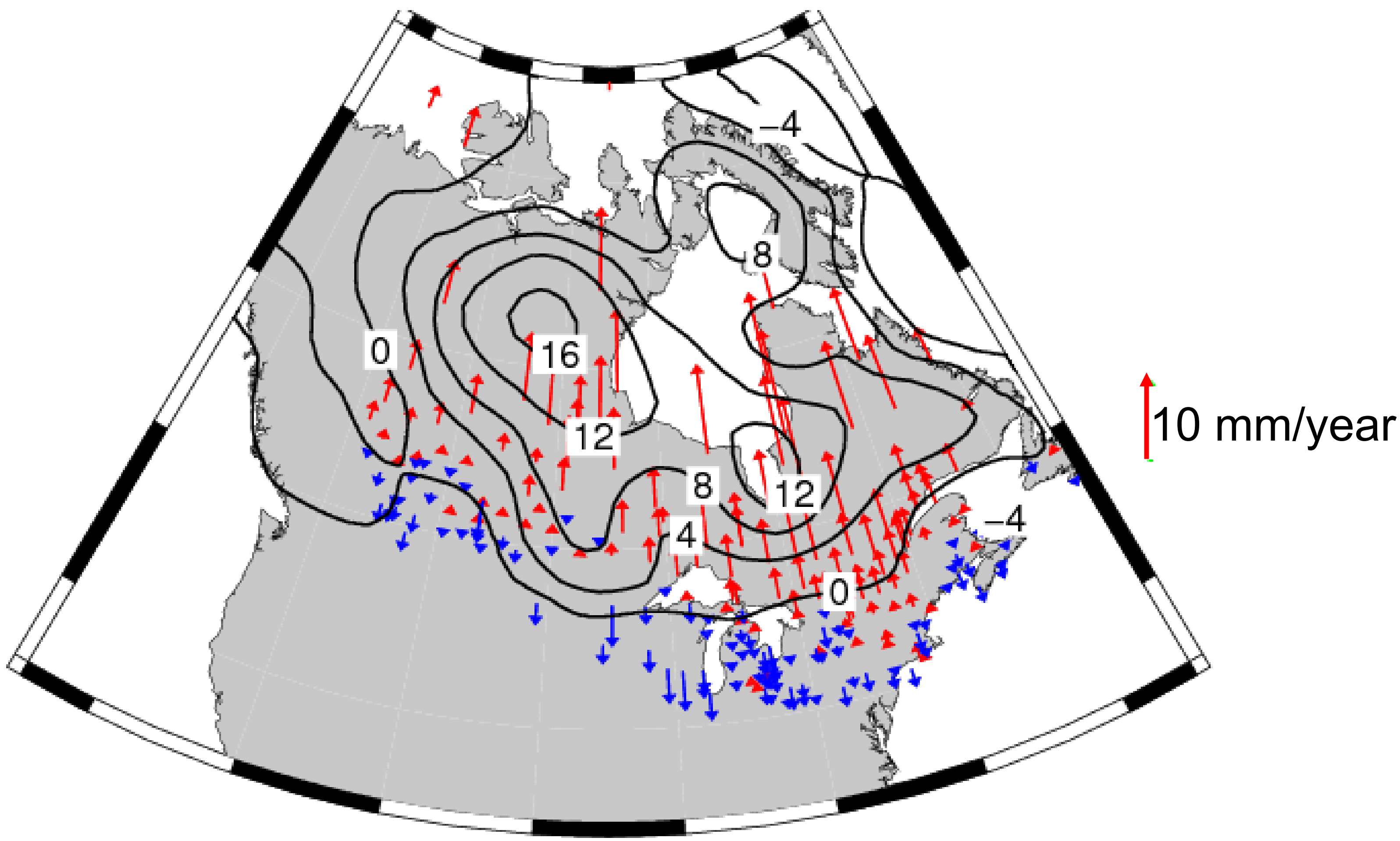
Standard GIA model



Uplift rate from Peltier submission to Special Bureau for Loading website

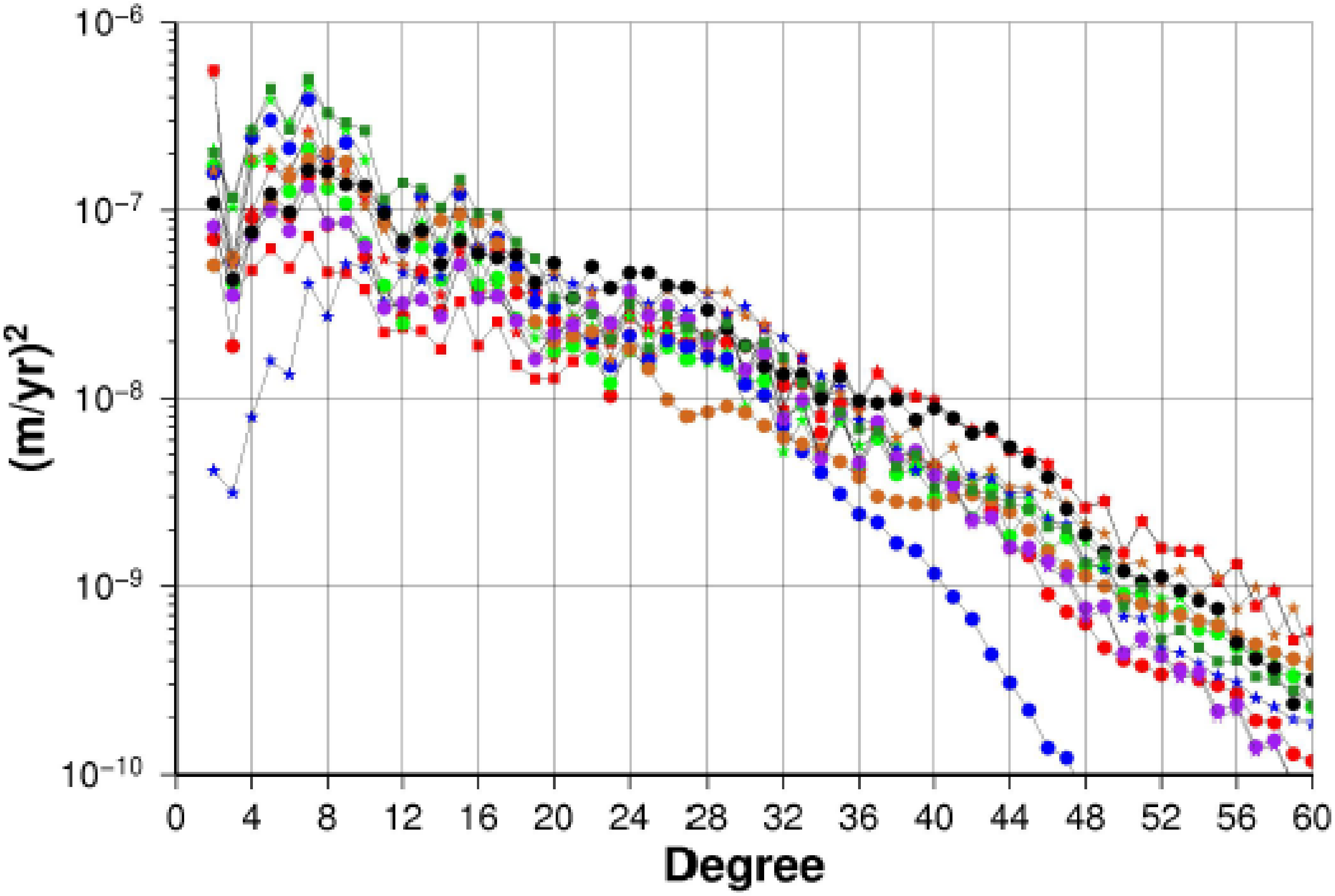
Standard GIA model

Contours: ICE-5G/VM2 **Arrows**: GPS uplift rates Sella et al. (2007)



van der Wal et al. (Canadian Journal of Earth Sciences 2009)

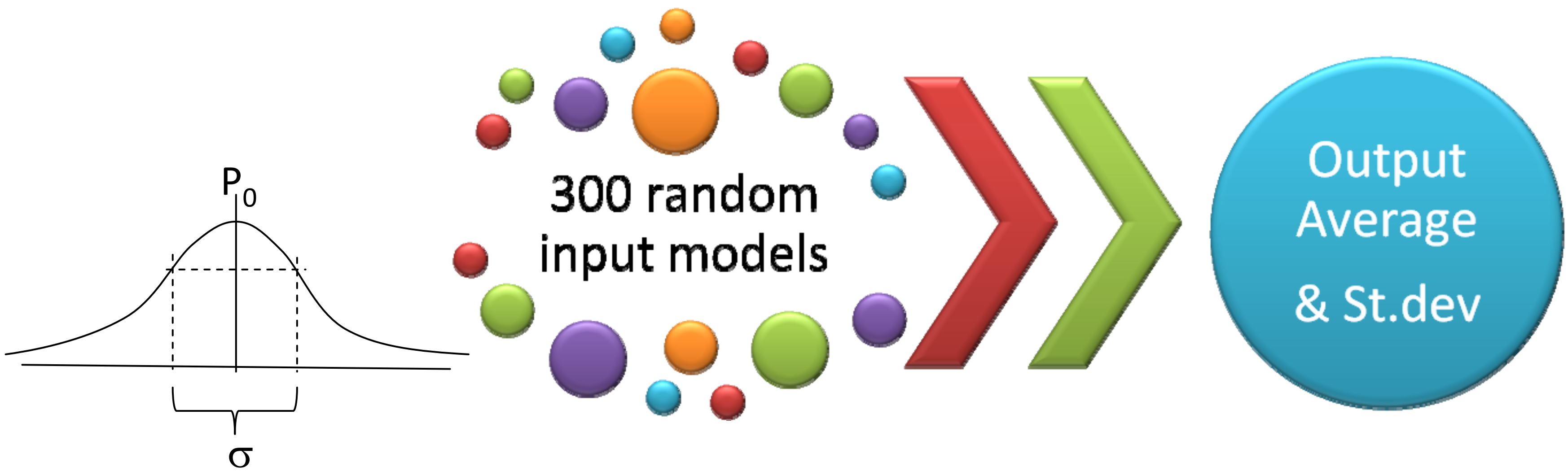
Uplift Rate Spectrum



Guo et al, J. Geodyn. (2012)

Method for uncertainty propagation

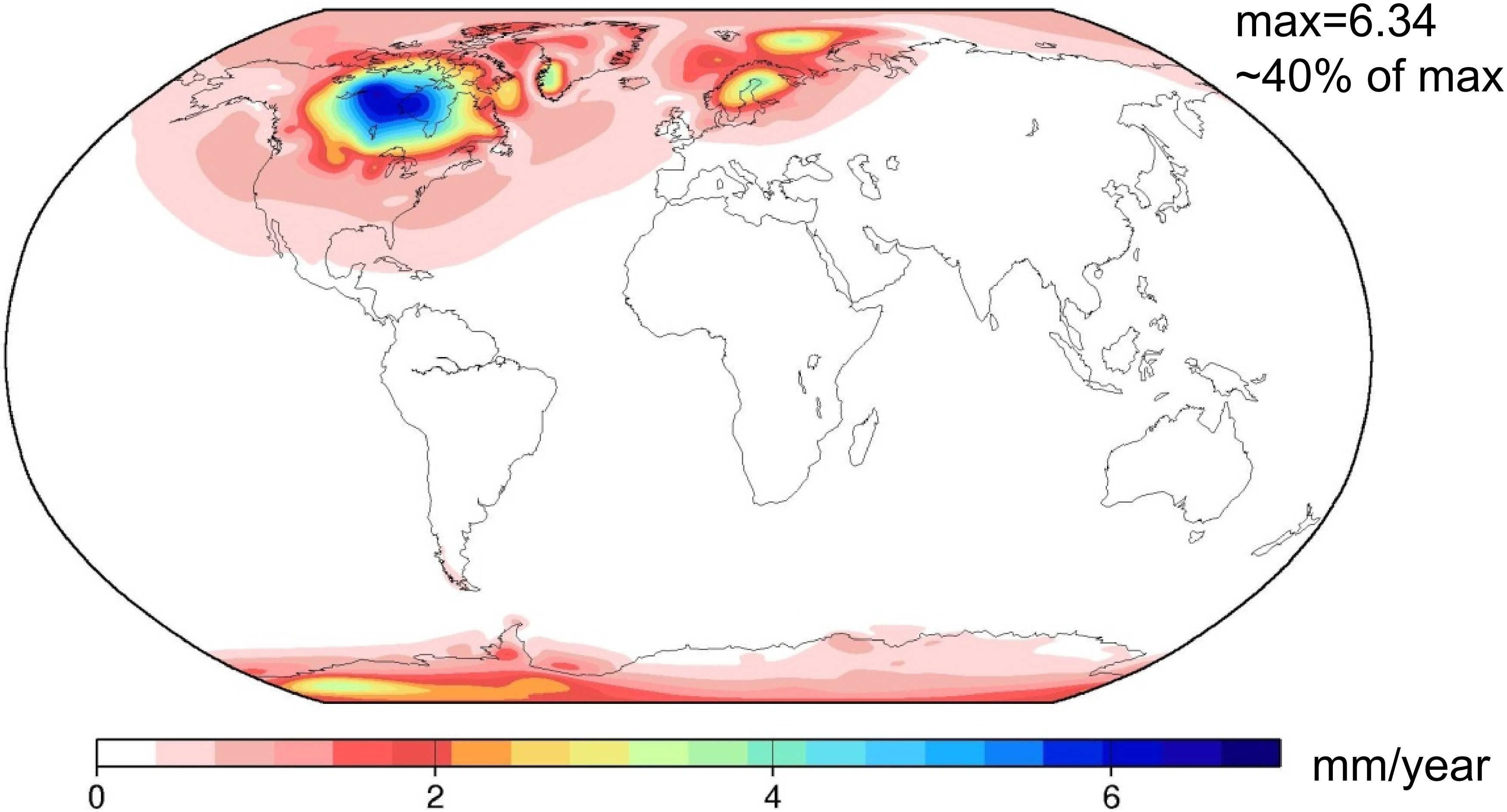
Monte Carlo Method:
hundreds of randomly generated input models with a Gaussian distribution with selected sigma around the input reference model P_0



Reference model:
Ice and Earth model: ICE5G (incompressible - 5Layer - VM2 – L90)

Uncertainty propagation: viscosity

Standard deviation



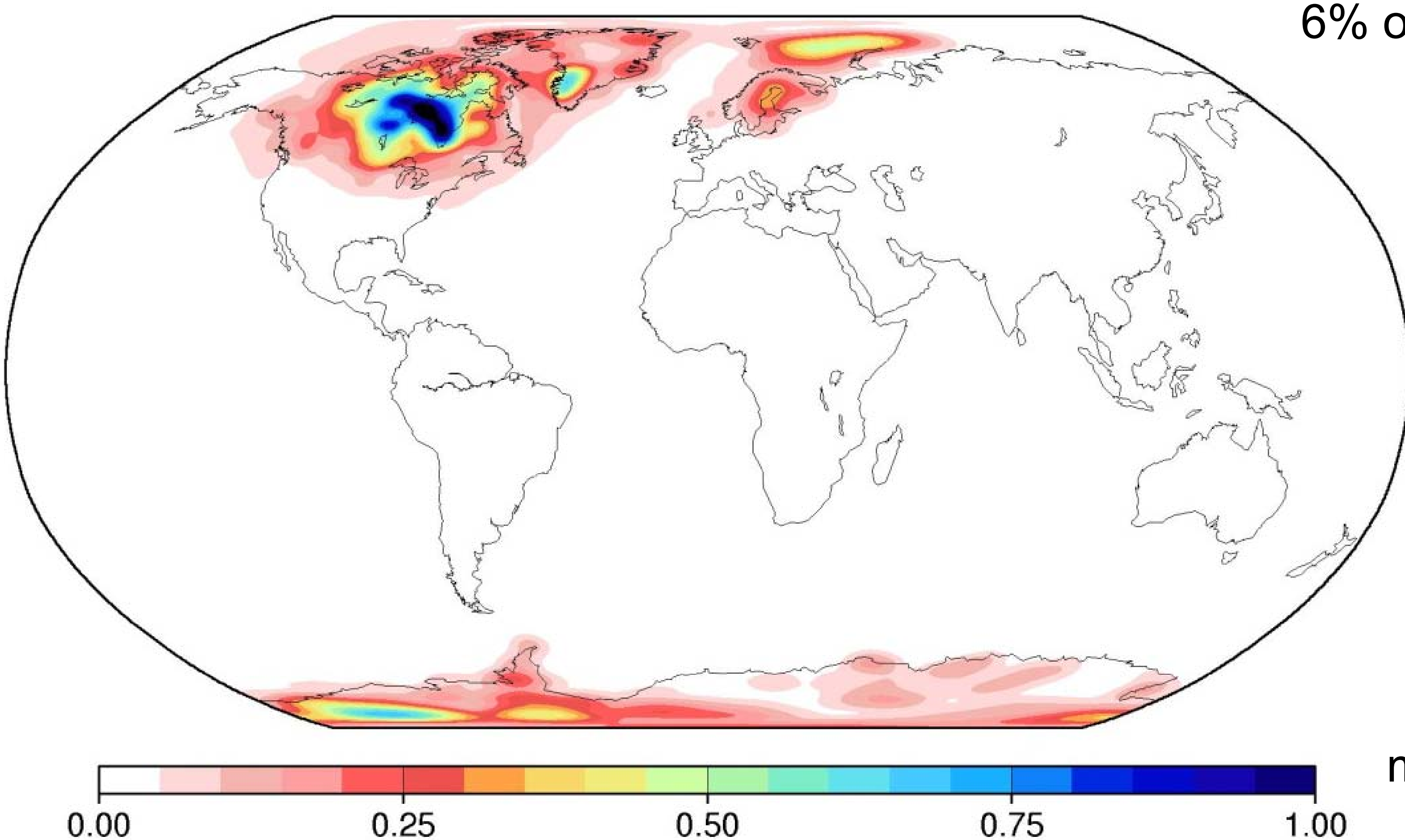
max=6.34
~40% of max signal

Variation of the viscosity by ± 0.3 in Log10 scale, i.e. by **$10^{\pm 0.3}$**

Uncertainty propagation: ice height

Standard deviation

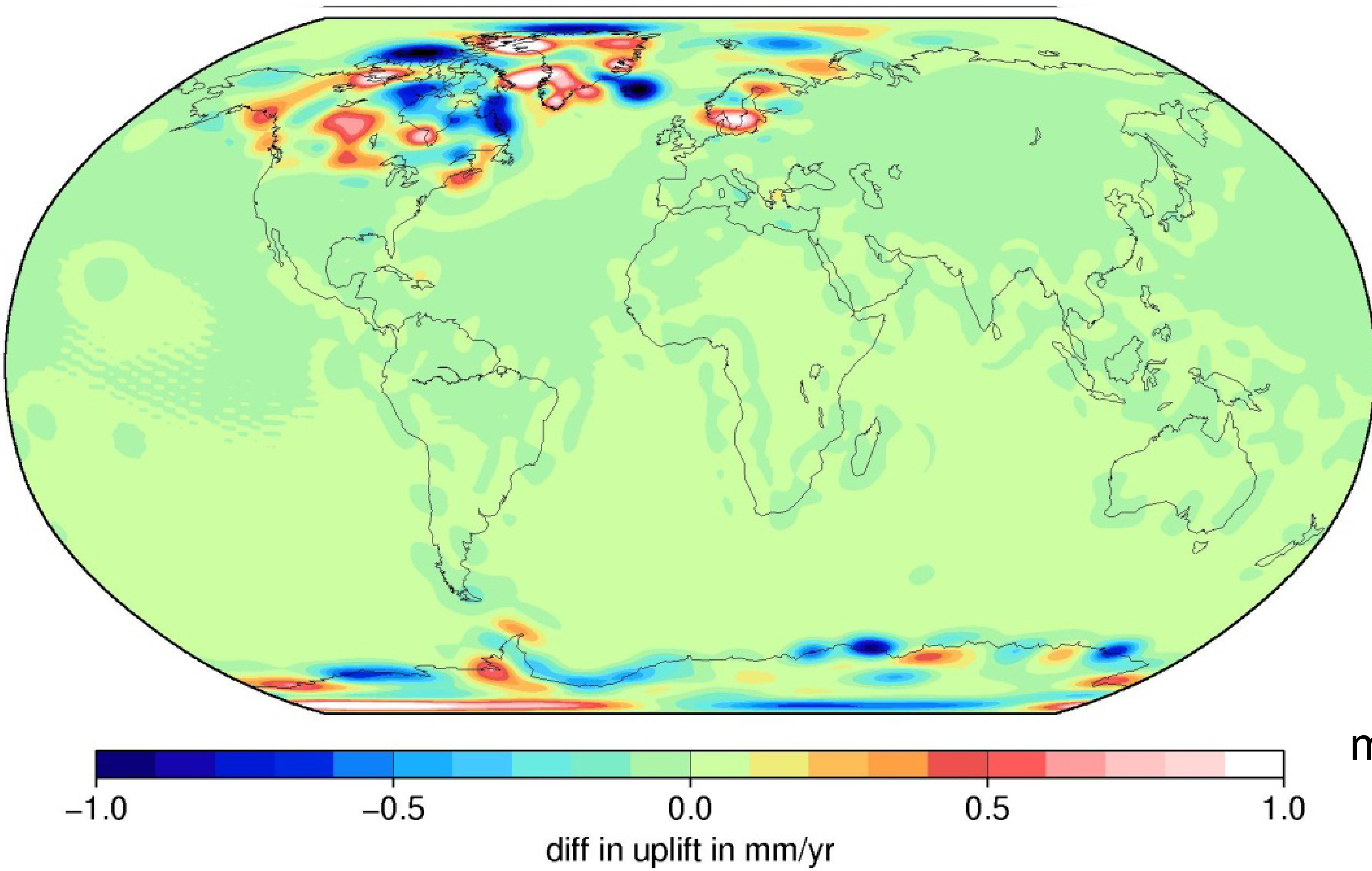
Max = 1.1
6% of the signal



I10: Variation of ± 30% of the Ice thickness for each time and location. Where *I*(t, w) is the same as today, we assumed a ± 10% variation for the ice< 800m.

Uncertainty: implementation

Difference in uplift rate



mm/year

Same Ice model ICE5G, Same Earth model VM2
Difference in initial sampling of the ice model and the ocean function

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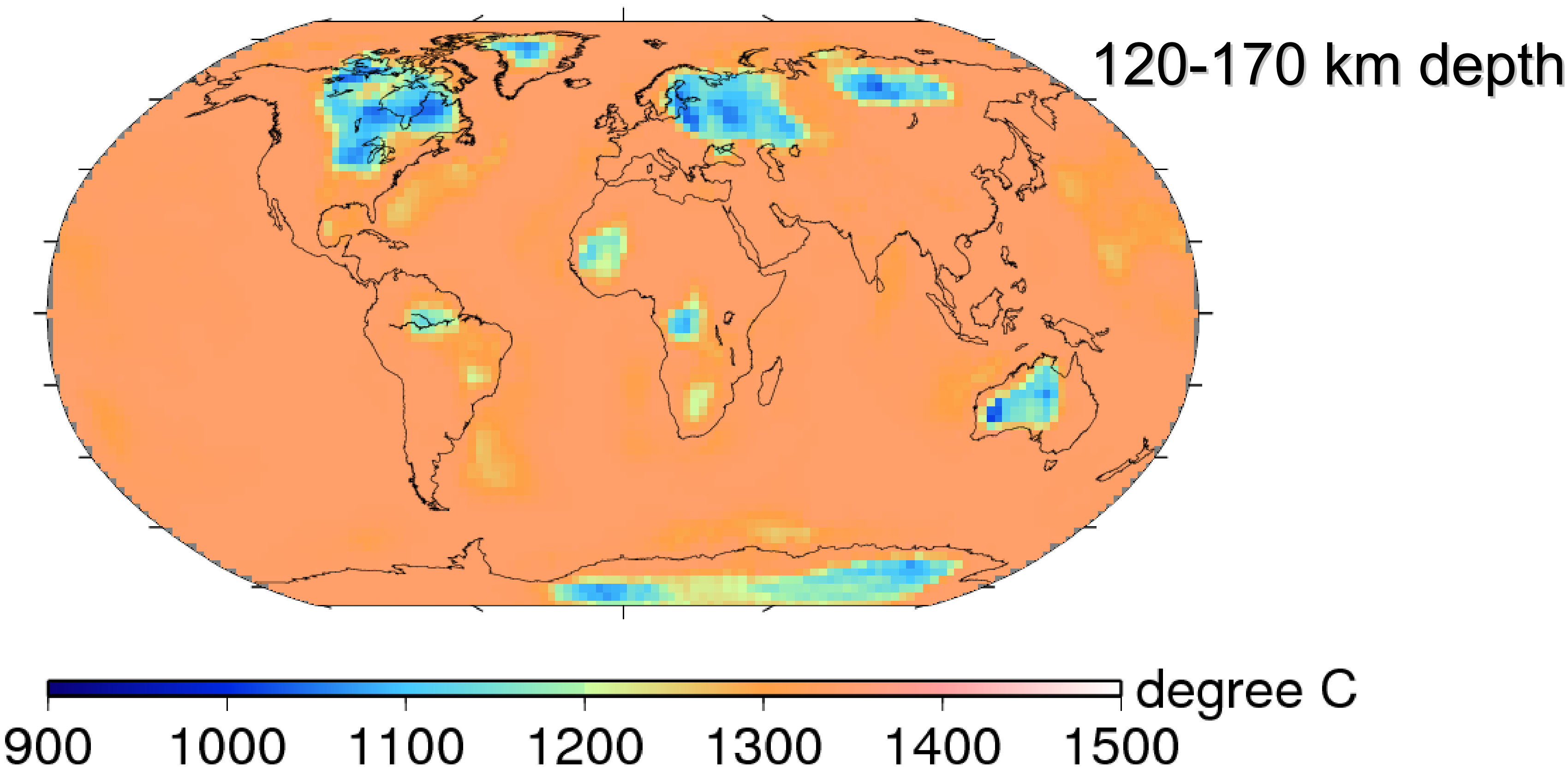
FINITE-ELEMENT MODEL

Uncertainty: lateral variation



- Heatflow measurements extrapolated by a global seismic model

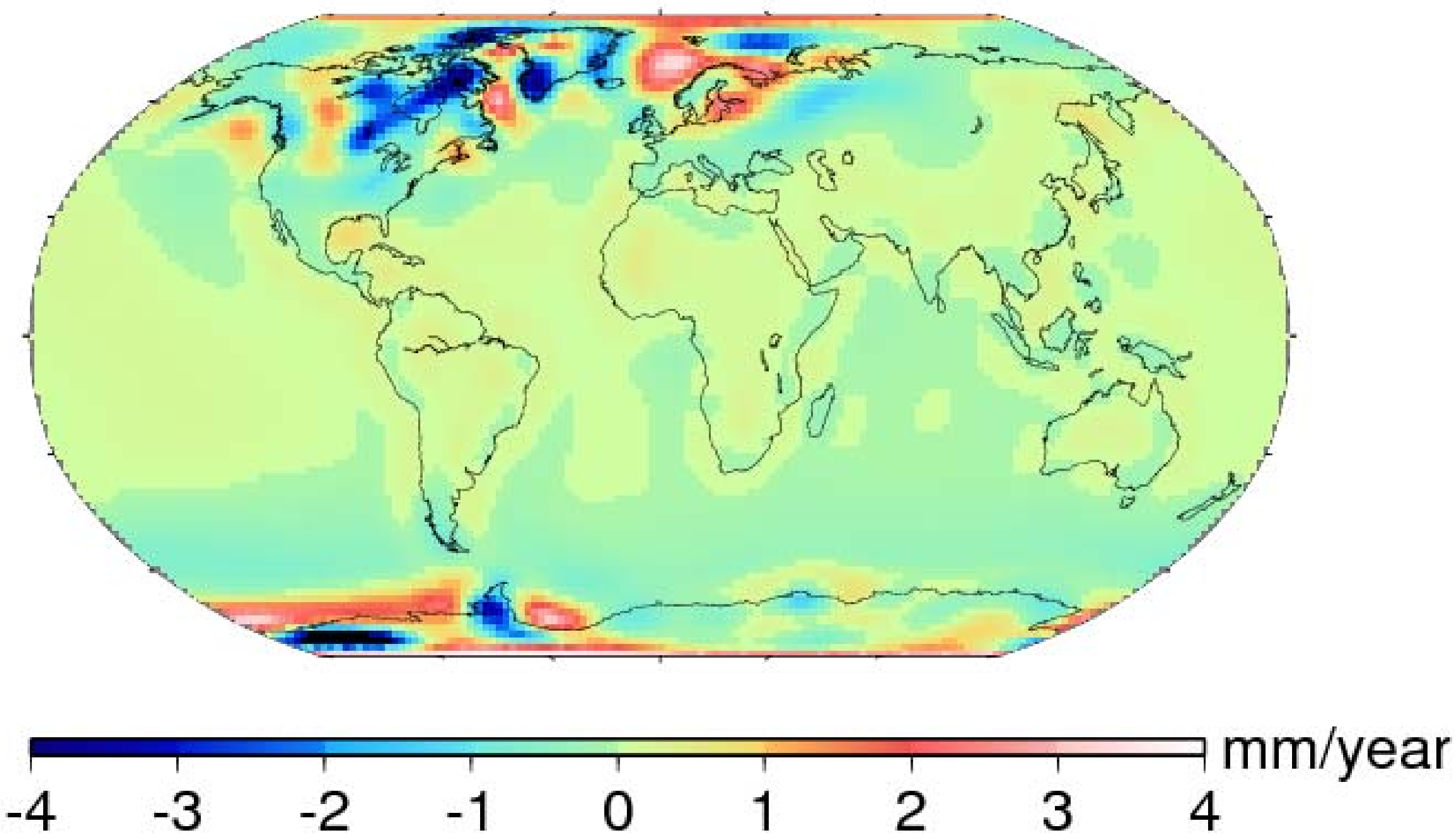
(Shapiro & Ritzwoller 2004)+ heat diffusion equation

van der Wal et al., (in prep.)

Uncertainty: lateral variation

Lateral varying – ICE-5G/VM2

-6.8 mm/year



van der Wal et al., (in prep.)

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Uncertainty: mantle deformation

Mantle rocks in the laboratory

$$\dot{\tilde{\varepsilon}}_{ij} = \left(\frac{3A_{n=1}}{2} + \frac{3}{2} A \tilde{q}^{n-1} \right) S_{ij}$$

S_{ij} deviatoric stress tensor

$\tilde{q}$ von Mises equivalent stress

n stress exponent (3.5)

From: Martyn Drury, Utrecht Univ.

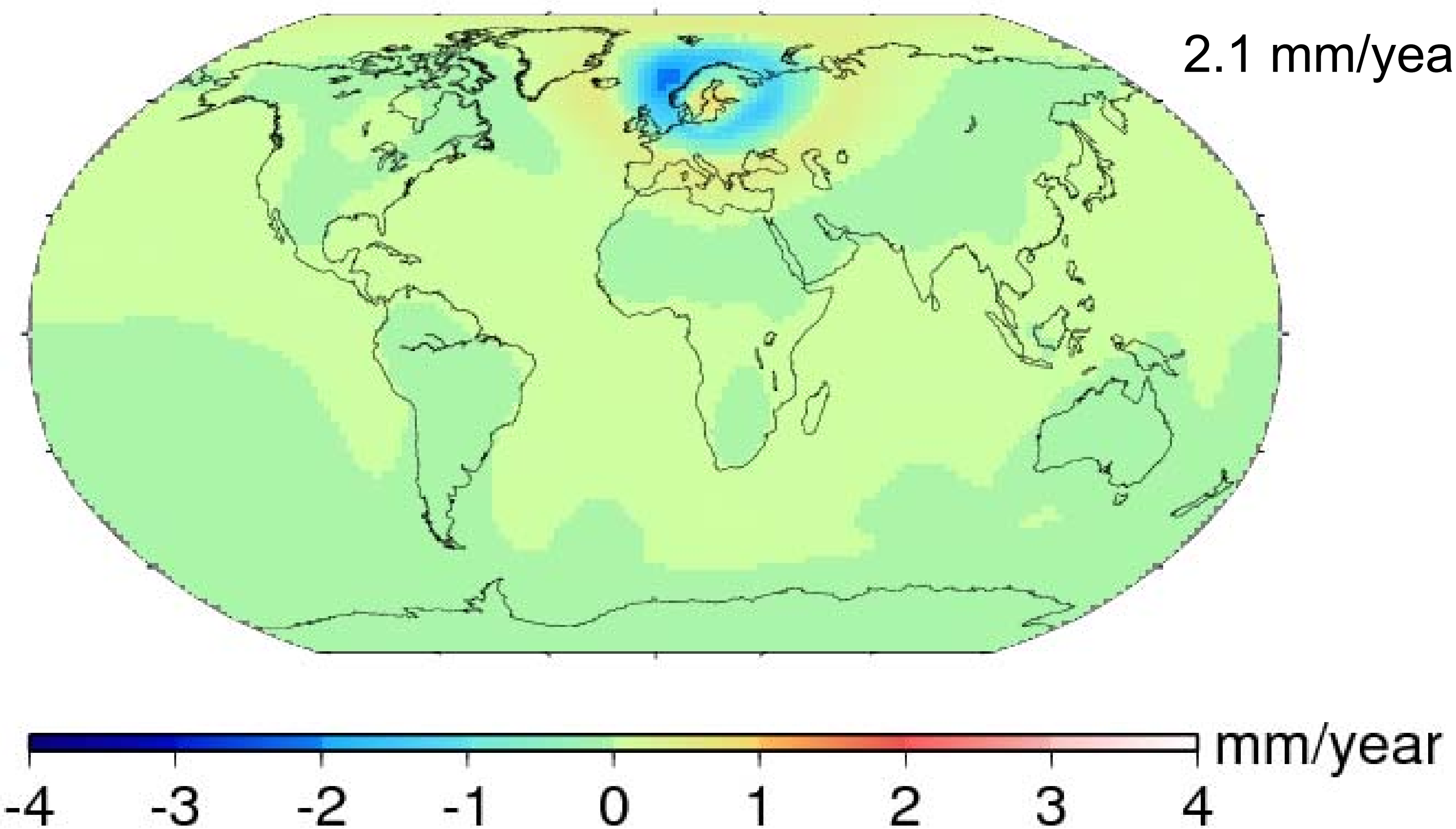
van der Wal et al., (in prep.)

Uncertainty: mantle deformation

Stress-dependent flow law

Max.

2.1 mm/year



van der Wal et al., (in prep.)

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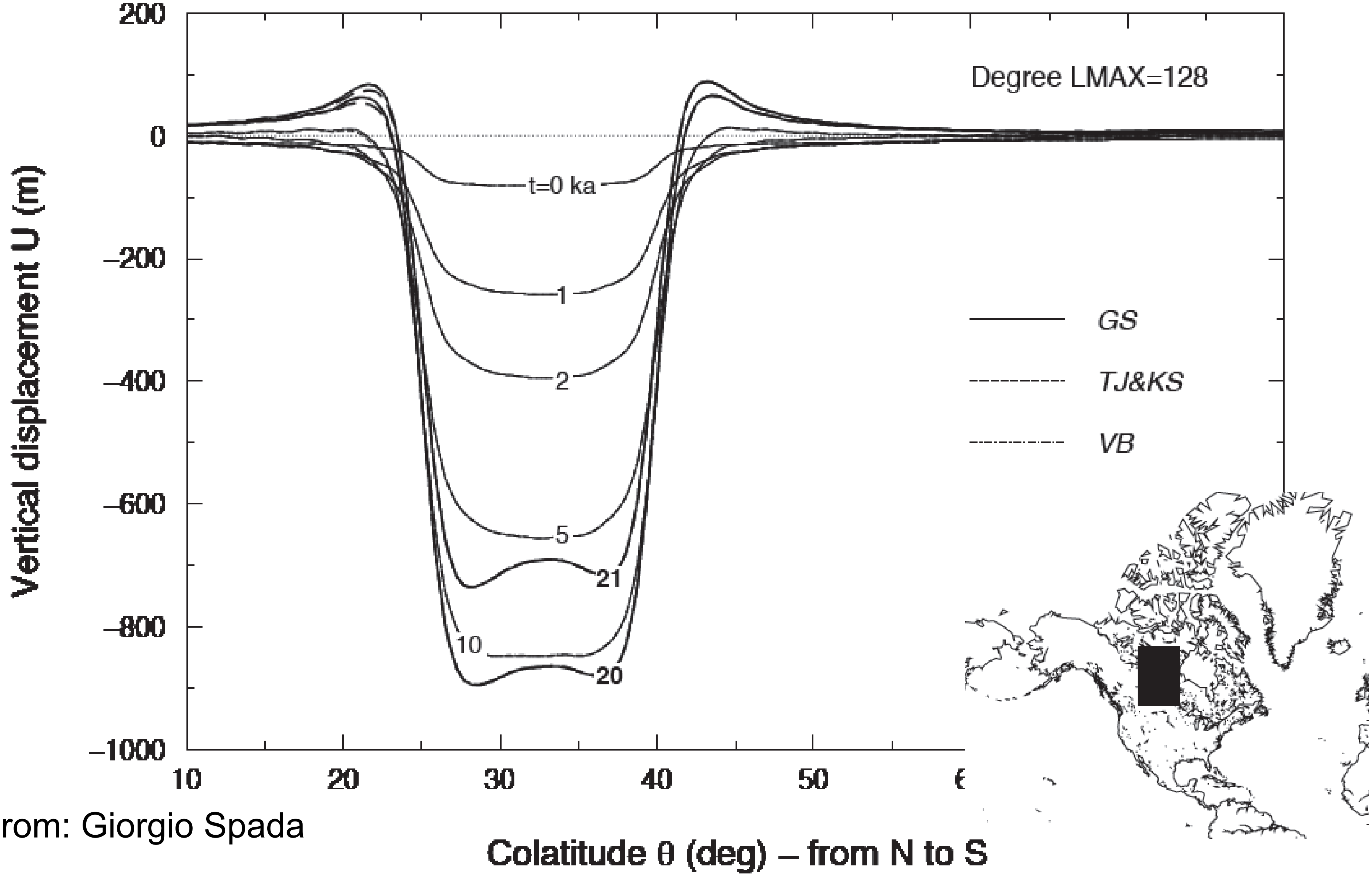
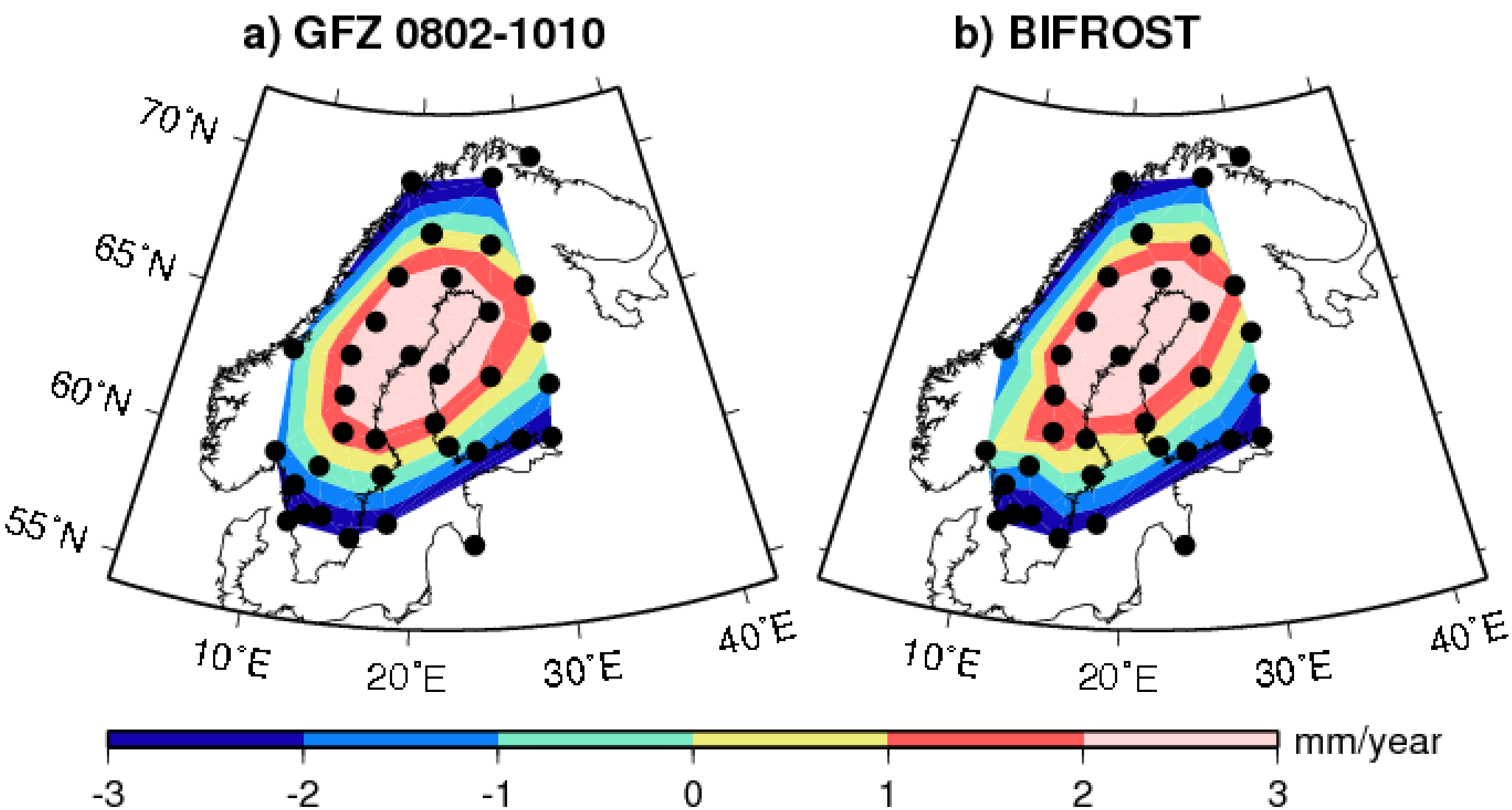
SOLUTIONS?

Solutions: Benchmark



From: Giorgio Spada

Solutions: Data



Van der Wal et al. (GJI 2011)

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Summary

Standard model: Viscosity - 6.3 mm/a, other Earth model – 1.9 mm/a, ice height - 1.1 mm/a, rotational feedback ??

3D: 6.8 mm/a, **Flow law**: 2.1 mm/a

Solutions:

- Use uncertainty estimate
- Benchmark
- Use other measurements
- Constrain the model for the region of interest
- Constrain the model with information from other Earth sciences

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Acknowledgements

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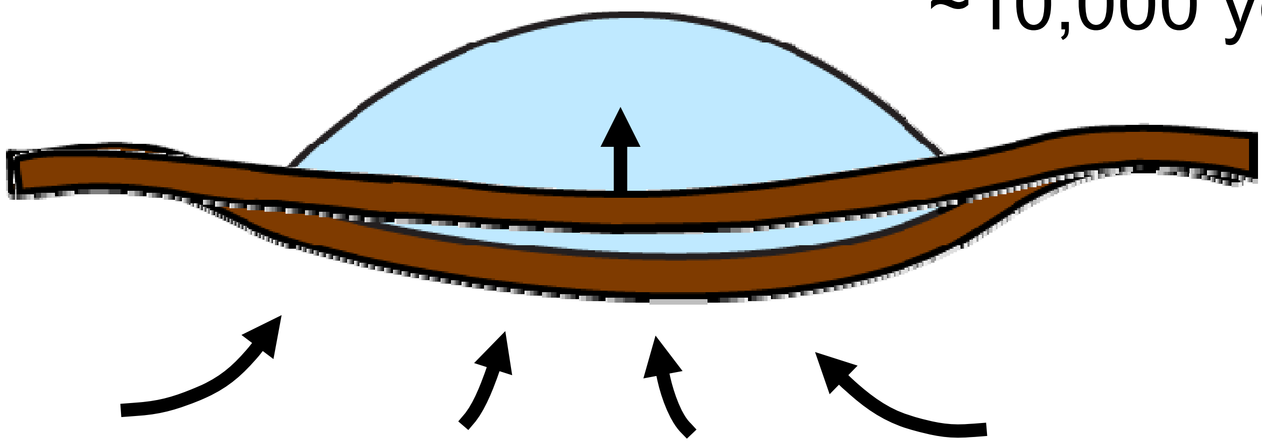
BACKUP SLIDES

Glacial Isostatic Adjustment (GIA)

rising

~10,000 years



Flow in the mantle determined by viscosity

Results: best fitting mantle viscosities

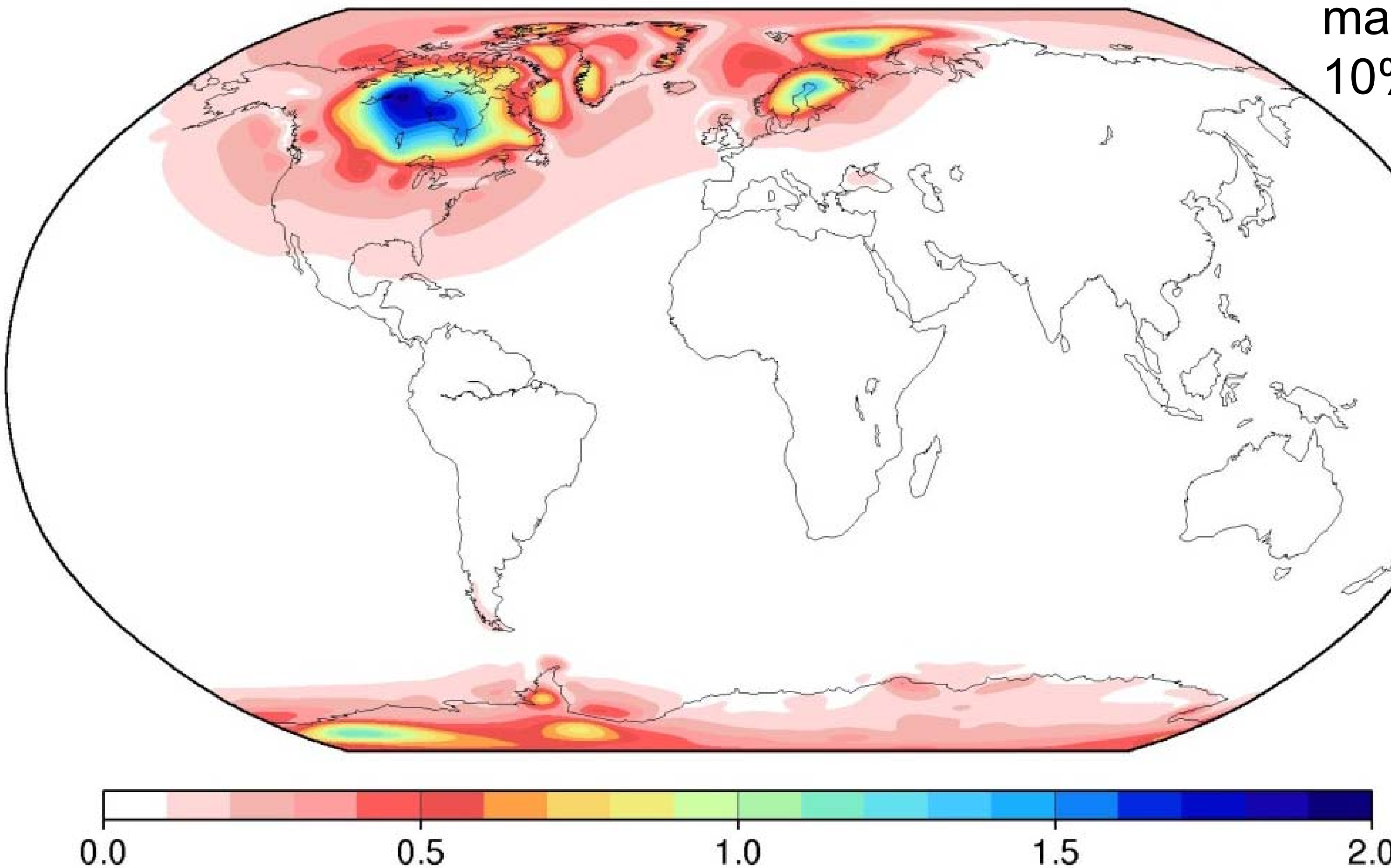
	η_{UM} [10^{20} Pas]	η_{LM} [10^{20} Pas]
Tushingham & Peltier (1991)	10	20
Mitrovica & Forte (2002	4	80
Kaufmann & Lambeck (2002)	7	200
Wolf et al. (2006)	3.2	160
Paulson et al. (2007)	5.3	23
GPS (ICE-4G)	8	32
GRACE (ICE-4G)	64	256
Historic sea level (ICE-4G)	16	32
Historic sea level (ICE-5G)	16	256

Van der Wal et al (GJI 2011)

Uncertainty propagation: Earth model

Standard deviation

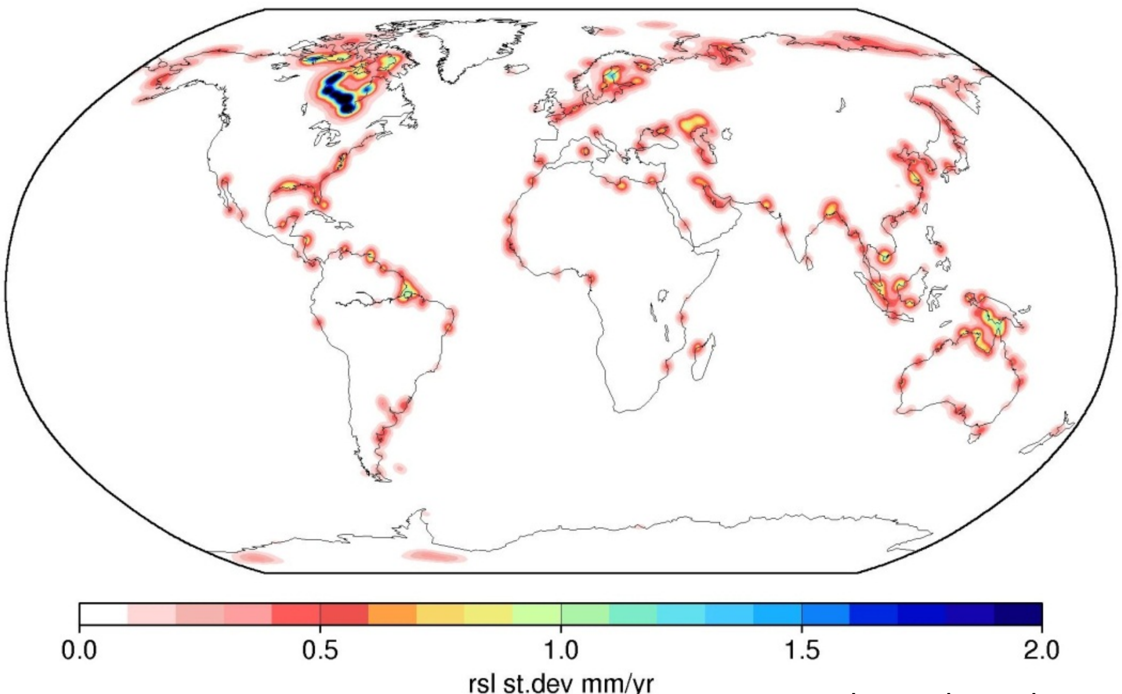
max=1.93,
10% of the signal

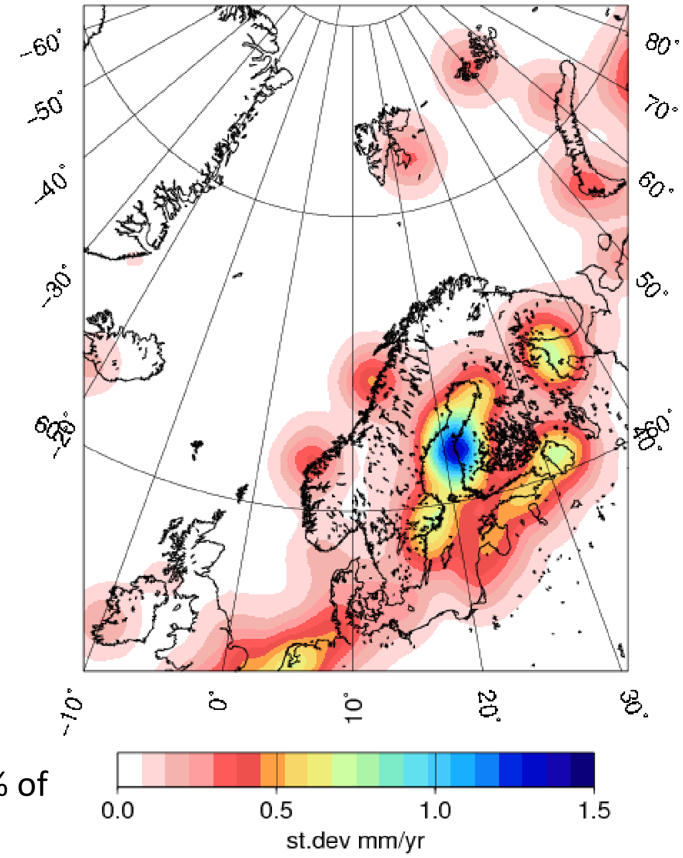


Variation of Lithospheric thickness ± 5 km, Density ± 5%, V_S ± 5%, and viscosity by ± 0.05 in Log10 scale

Propagation of Ocean Function uncertainties

St. Dev for RSL (GPS and tide-gauges)

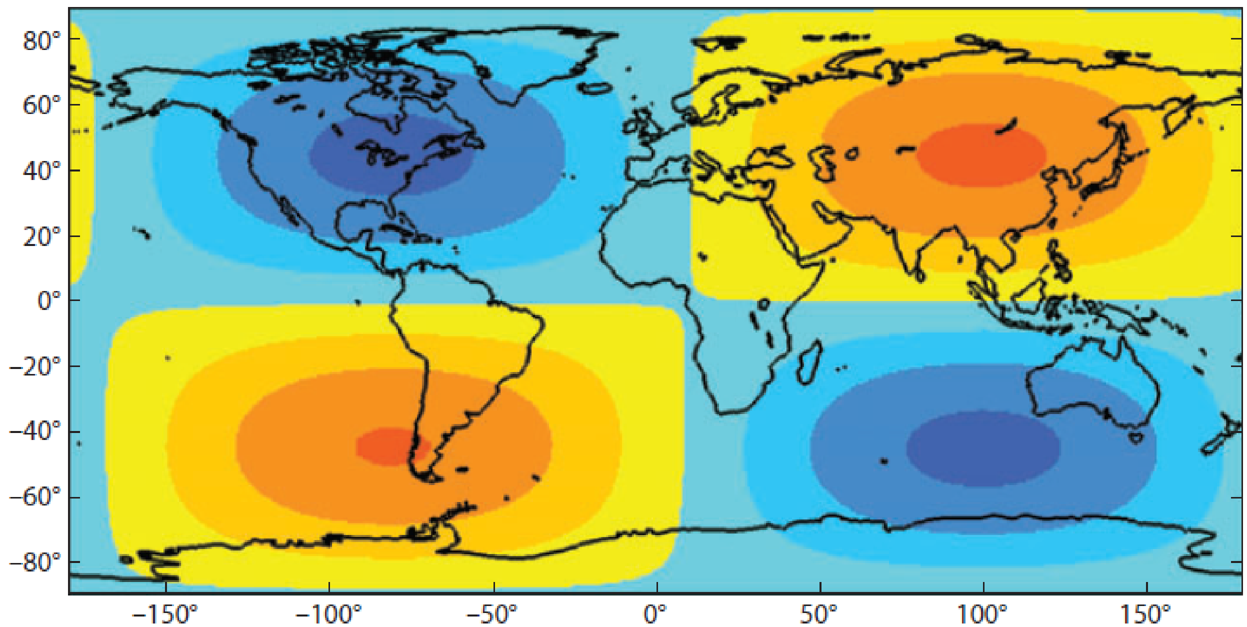




The scale is about 15% of the whole signal.

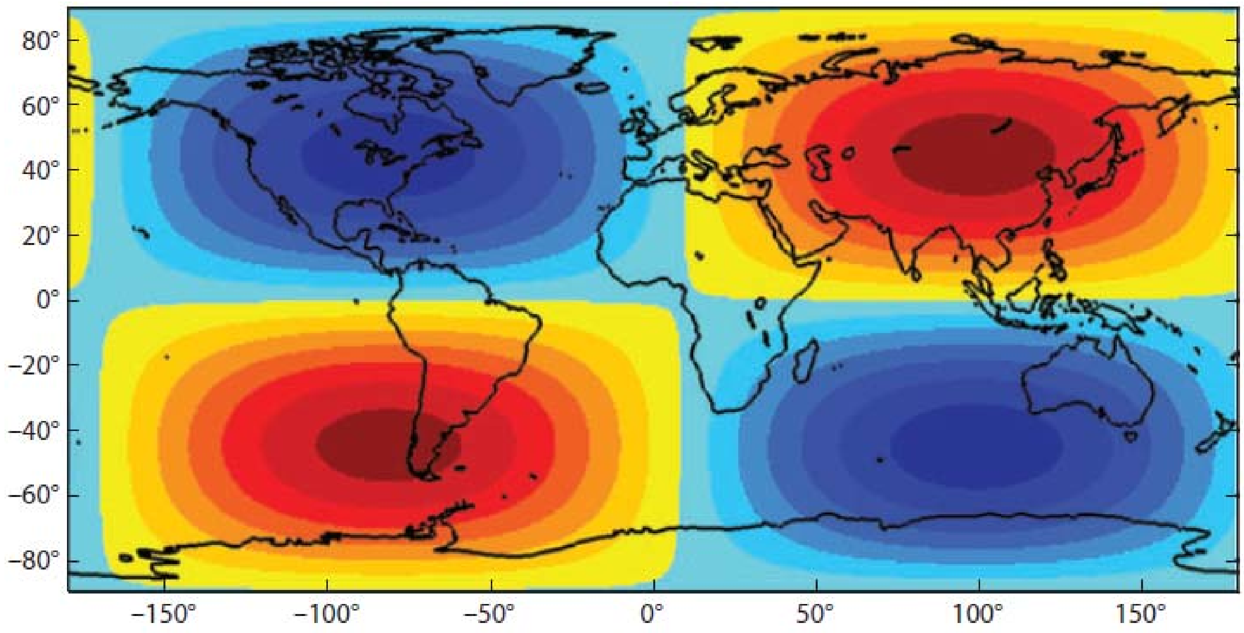
O2: Variation of ± 10% of the paleotopography *T*(t, ω) for each time t and only in locations (ω) within a belt following the shorelines. From the paleotopography then we compute the ocean function *FO*(t) by setting *FO* = 1 where the paleotopography is negative, and FO = 0 otherwise.

Uncertainty propagation: rotational feedback



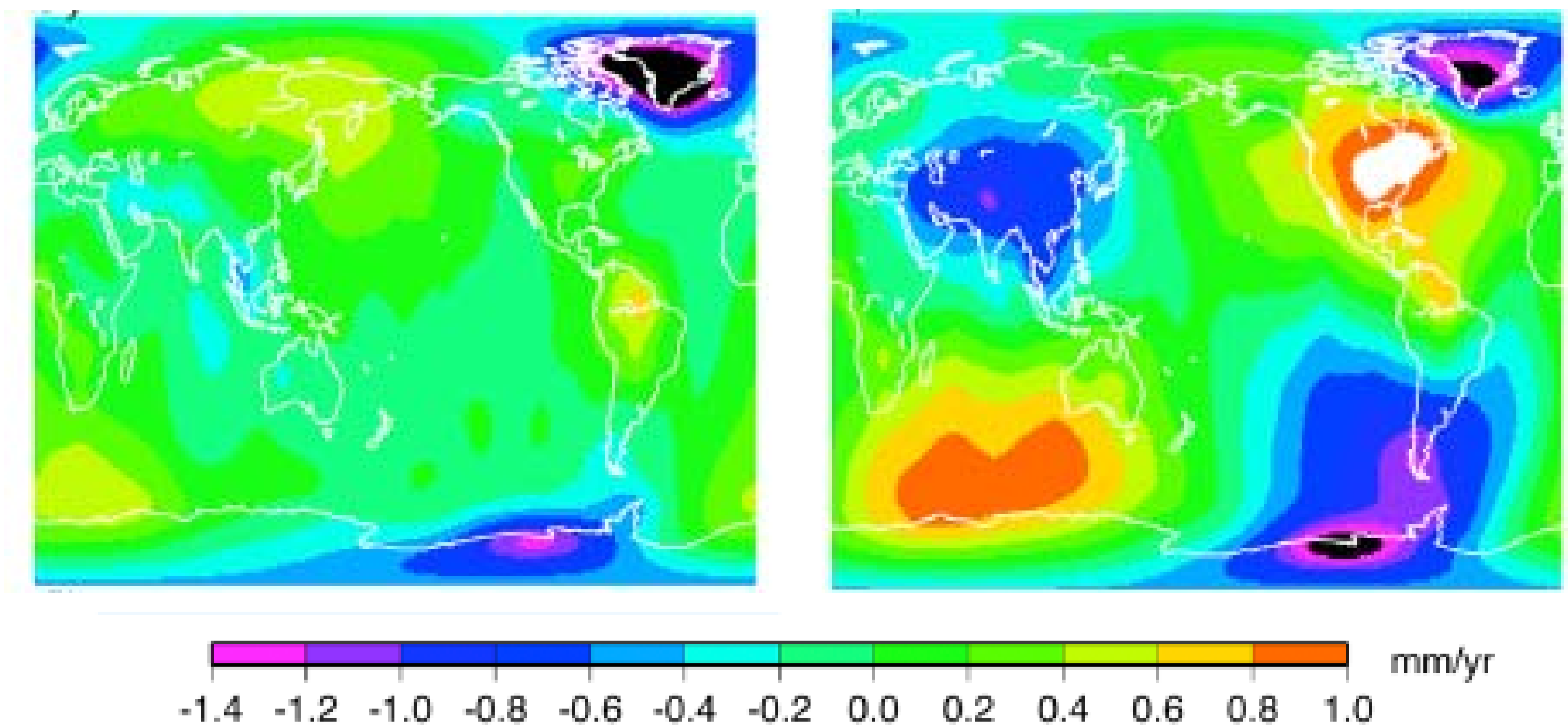
Mitrovica & Wahr, Ann. Rev. Earth Planet. Sci. (2011)

Uncertainty propagation: rotational feedback



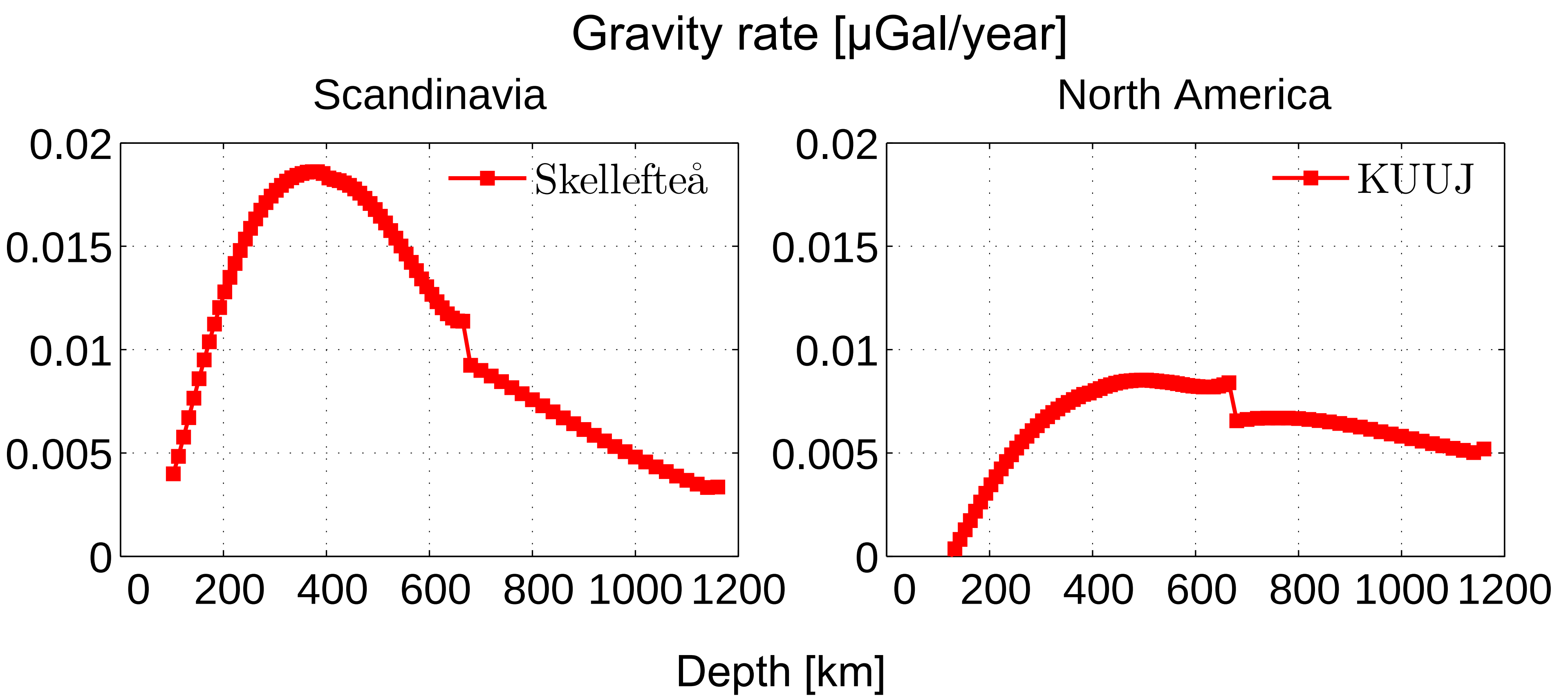
Uncertainty: rotational feedback

GRACE – Paulson et al (2007) GRACE – Peltier (2004)



Chambers et al., JGR (2010)

Sensitivity kernels



Gravity rate (uplift rate) in North America is more sensitive to the lower mantle viscosity

Van der Wal et al. (GJI 2011)

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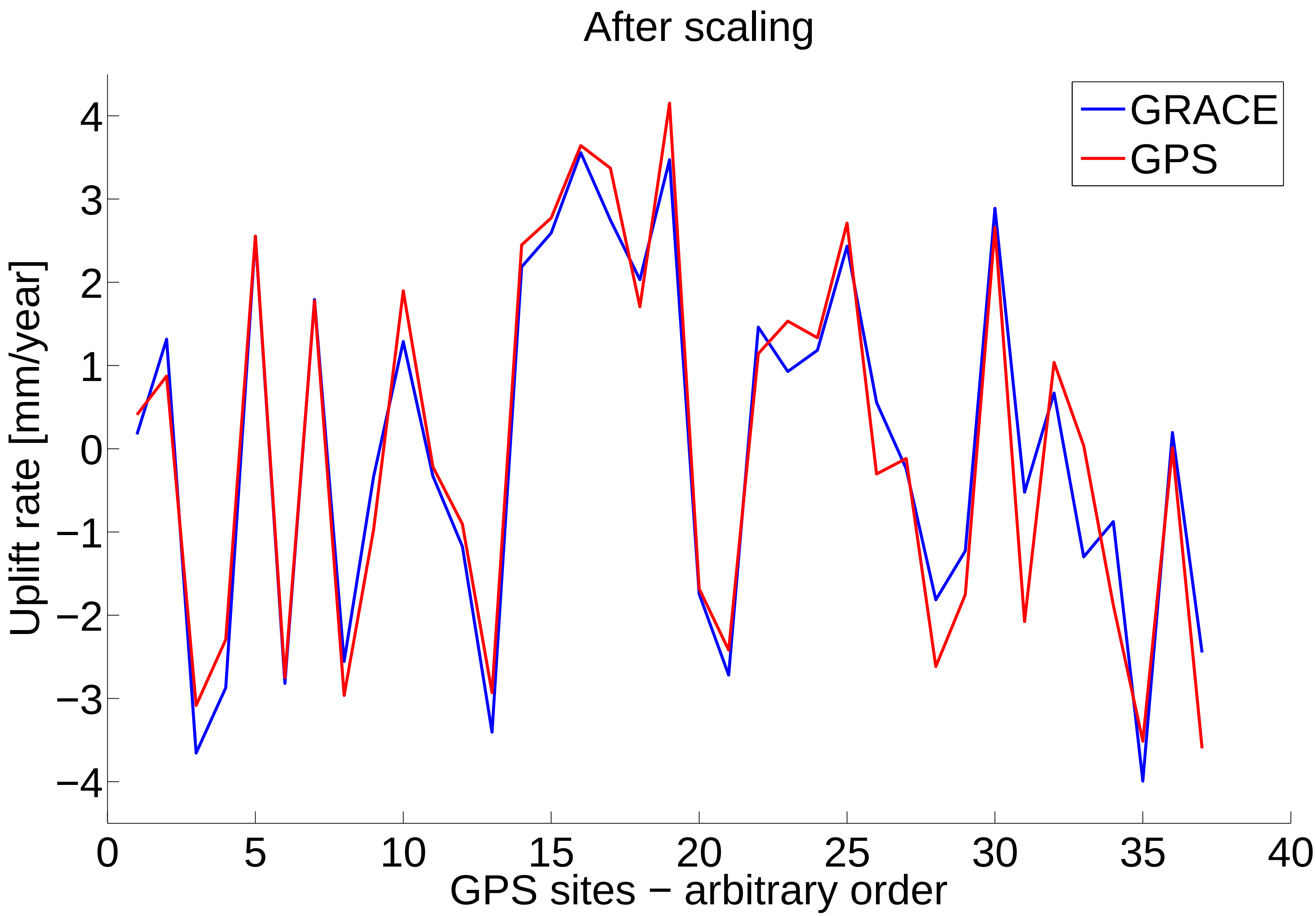


After scaling
GRACE
GPS
Uplift rate [mm/year]
4
3
2
1
0
−1
−2
−3
−4
0
5
10
15
20
25
30
35
40
GPS sites − arbitrary order

Model

CR — Crust (fully elastic)

35

70

120

UM — Temperature

170

230

400

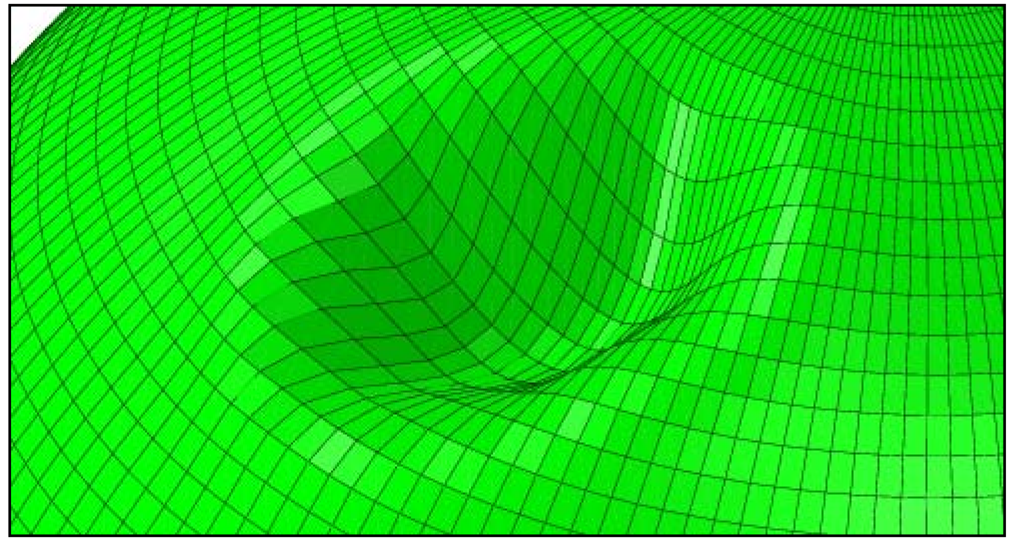
TZ

670

LM — Best fitting composite rheology parameters of van der Wal et al. (2010)

1170

2890



Model

Hirth & Kohlstedt (2003)

$$\dot{\varepsilon} = A_D \sigma^n d^{-p} fH_2O^r \exp(\alpha\phi) \exp\left(-\frac{E+pV}{RT}\right)$$

A_D pre-exponent factor

n stress exponent (3.5)

d grain size (0.5–4 mm) Kukkonen&Peltonen (1999)

fH_2O water fugacity

Φ melt factor (0)

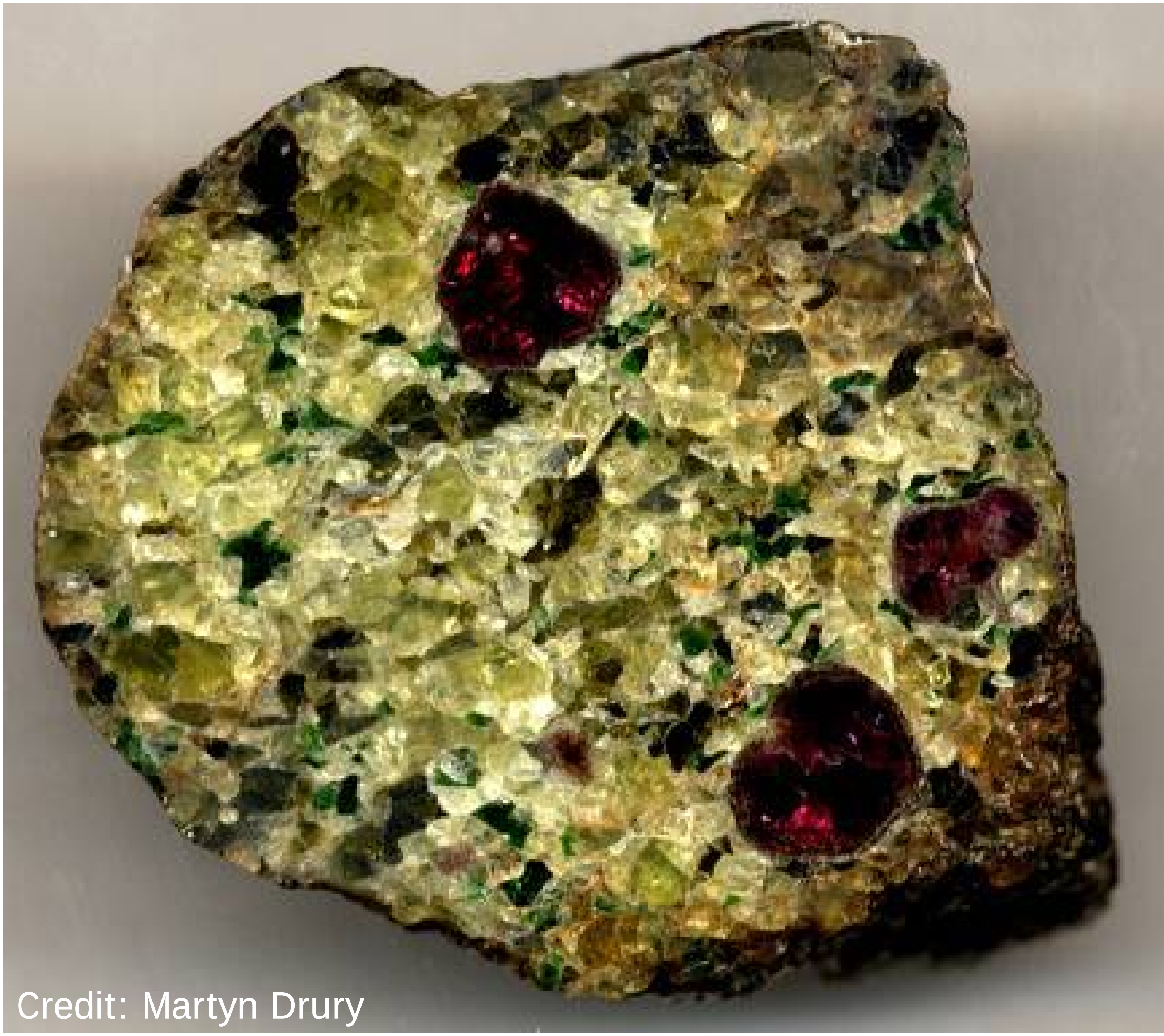
E activation energy

P pressure

V activation volume

T temperature

R gas constant



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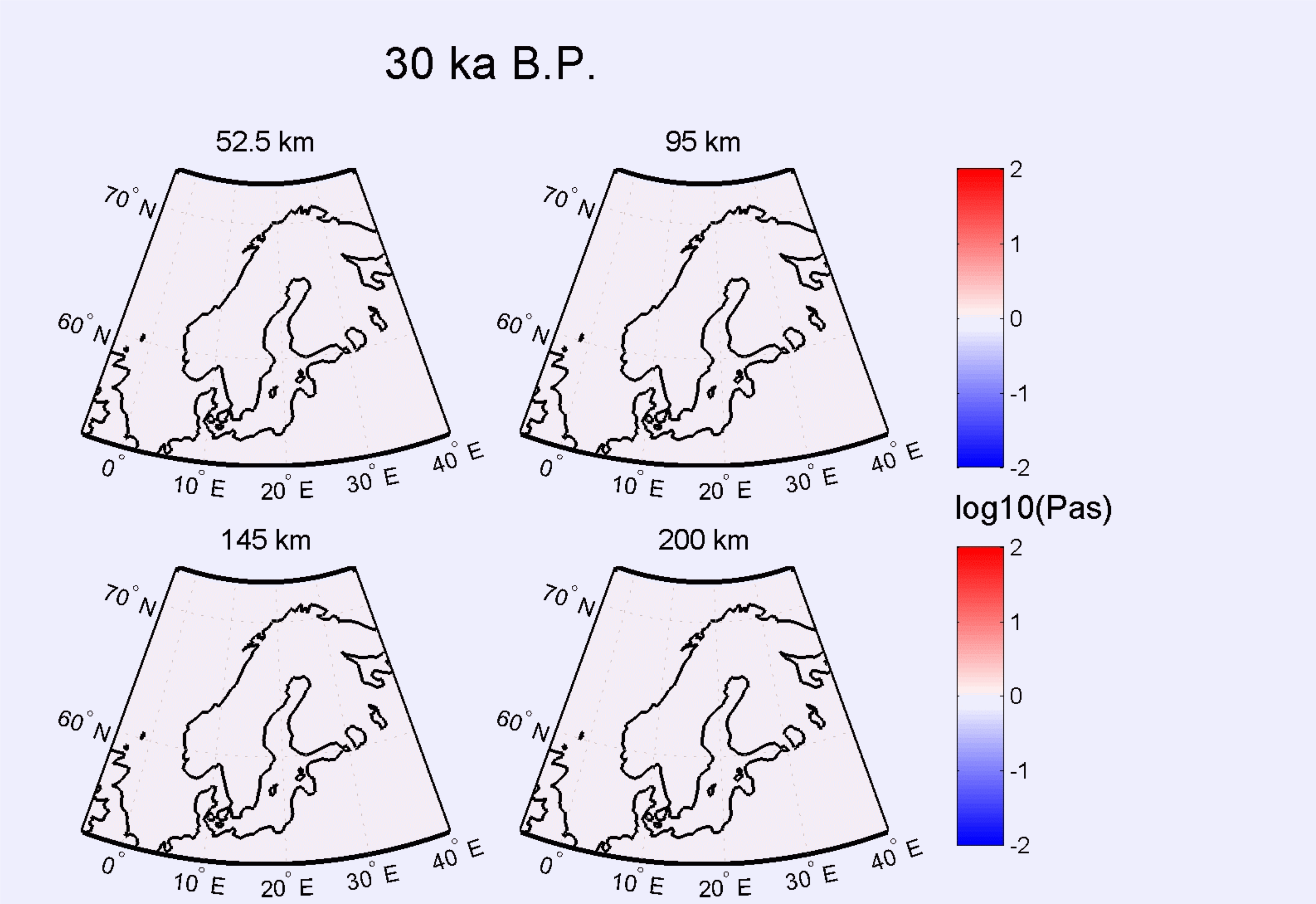
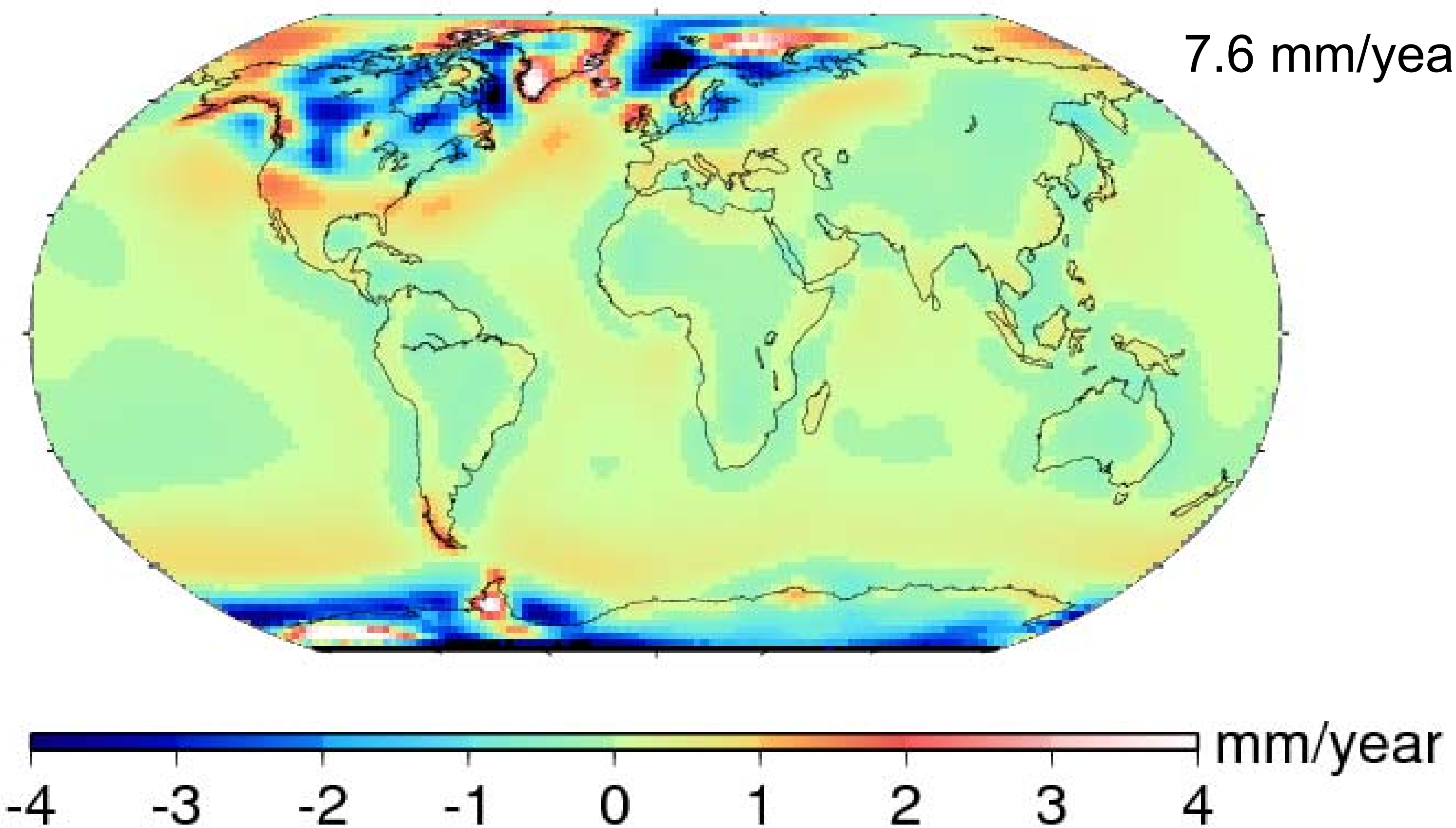


Barnhoorn, van der Wal, Drury, Vermeersen (G-cubed 2011)

Uncertainty: 3D temperature

Temperature II – Temperature I



Max.

7.6 mm/year

van der Wal et al., (in prep.)

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